ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

STUDY OF THE INFLUENCE OF FREQUENCY INVERTERS IN ELECTRIC MOTOR DRIVE THROUGH TECHNICAL PREDICTIVE

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Abstract. *The drive motors are three-phase AC drives for a solution is relatively new, but already widely used in industry. Thus the professionals who work with predictive techniques have little knowledge about the behavior of frequency inverters, which motivates the development of this research. This paper presents a contribution to the study and characterization of failures in induction motors fed by frequency inverters using the technique of Vibration Analysis and Analysis Module Variable Frequency Drive (VFD). The vibration signals were collected using Microlog GX-75, SKF technology. The signals for analysis via the VFD module were collected through the Explorer 4000, technology SKF/Baker. The influence of frequency inverters in electric motor drives through predictive techniques mentioned above is essential for the identification of deterministic frequencies and vibration levels acceptable. Thus it is possible interventions planned and monitored in rotating equipment mainly increase the availability and reliability of electric motors present in plants.*

Keywords: *Technical Predictive, Total Harmonic Distortion(THD), Analysis Module Variable Frequency Drive (VFD), Vibration Analysis.*

1. INTRODUCTION

The evolution of the world economy associated with globalization has contributed to the rise of new consumer markets, especially the emerging economies like Brazil. This scenario associated with an increasingly competitive economy has shown a constant need to improve the resources and costs, making it necessary to make full use of the entire productive capacity. As a result, organizations are constantly seeking new management tools, that directed toward greater competitiveness through quality and productivity of its products, processes and services, Kardec e Nascif (2009).

With the development of power semiconductors with excellent performance characteristics and reliability, it was possible to implement systems, electronic speed variation. Over the years the frequency inverters appear as a novelty in terms of improvement, allowing a considerable reduction in power consumption, improving the performance of machines due to the adaptation of the speed to process requirements, elimination of the peak current at the start of engine, reducing the frequency of maintenance of equipment, Mascheroni and Lichtblau (2002). With the steady growth of the economy of ideas, the variation of rotation equipment via frequency inverters proved the solution to reducing costs, Gurgel (2006).

Due to the development of the industrial park and the importance of equipment that compose it becomes imperative to implement effective maintenance, ie not only know when an equipment or mechanical component will fail, but also understand the behavior of this, before the different operation regimes, Weidlich (2009). It is not acceptable to live with the breakdown and unscheduled corrective maintenance, making it necessary monitoring through predictive techniques.

Predictive maintenance, among all other forms of maintenance, is what has made more cost effective. The result of their correct deployment means fewer interventions in the industrial plant, lower inventories and higher equipment reliability. Predictive maintenance is the first major paradigm shift maintenance and its implementation is the result of managerial policies aimed at unplanned corrective maintenance, which has brought significant gains for companies that adopted it.

Rotating machines (motors, compressors, fans, pumps etc.) are present in all industrial processes. According Trevisan (2010), in the petrochemical industry, for example, over 95% of equipment is rotary.

Due to the growing technological development, most recently rotating machinery present in the industry are driven by AC drives that can be both vector and scalar type. The inverter climb is indicated for soft starting, operating above the rated engine speed and constant operation reversals. The vector inverter is designed for high torque at low speed, precise control of speed and torque adjustable.

In the paper presentations of research groups on technical, scientific congresses, maintenance professionals and researchers have motivated us to intensify studies on fault detection such equipment including inverters. There is great interest in understanding the behavior of frequency inverters (their frequencies deterministic modulations, harmonic, among others) in order to include them in a predictive maintenance program.

The drive motors are three-phase frequency inverters for a solution is relatively new, but already widely used in industry. Professionals working with predictive techniques have little knowledge about the behavior of frequency inverters, which motivates the development of this research.

This work presents a contribution to the study and characterization of faults in induction motors fed by frequency inverters using the technique of Vibration Analysis and Analysis Module Variable Frequency Drive (VFD). The vibration signals were collected using Microlog GX-75, SKF technology. The signals for analysis through the VFD module were collected through the 3000 Explorer, technology SKF / Baker. Both technologies are available in LASID (Laboratory of Dynamical Systems) which were carried out experimental tests.

The influence of frequency inverters in electric motor drives through predictive techniques mentioned above is crucial for the identification of deterministic frequencies and vibration levels acceptable. Thus it is possible interventions planned in rotating equipment monitored and mainly increase the availability and reliability of electric motors present in industry parks.

2. FREQUENCY INVERTER

The induction motor subjected to a PWM voltage, from a frequency inverter, will be subject to voltage harmonics (frequency components above the fundamental frequency). Depending on the PWM used, the switching frequency and other particularities of control, the engine may display increased temperature loss, loss of income and increased levels of vibration and noise when compared with sinusoidal supply.

In Eq. 1 we have the harmonic current of order "n" (In) is equal to the number of pulses of the converter (n) times an integer row (k) (e.g. 1,2,3 ...) more or less 1.

$$In = (n \times k) \pm 1 \tag{1}$$

The presence of these harmonics produce changes in activation as components of torque acting in the opposite direction of the fundamental, as occurs with the 5°, 7°, 11° etc. harmonics. This means that how much the 5th to the 7th produce a resultant 6th harmonic oscillations that can stimulate mechanical systems in motor load or turbine-generator due to a potential excitation of mechanical resonances, IEEE (1991).

3. THD - TOTAL HARMONIC DISTORTION

According to the User's Manual Baker Explorer 3000, the EXP3000 examines the Total Harmonic Distortion (THD) of the three single phases to neutral voltages. It assesses the voltage distortion level compared with stored thresholds.

A typical equivalent circuit of a three phase induction motor is shows on Fig.1, when Rs is stator resistance; Ls is stator inductance; Lr is rotor inductance; Rr is rotor resistance; Lm is magnetizing inductance and R_{load} is equivalent resistance which dissipated power models the load. On the other hand Fig. 2, shows equivalent circuit for frequencies other than 60Hz fundamental.

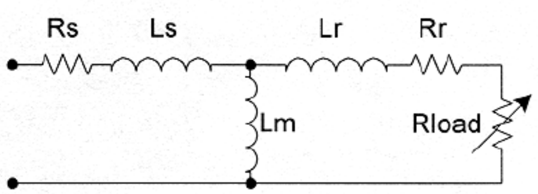


Figure 1. Typical equivalent circuit of a three phase induction motor.

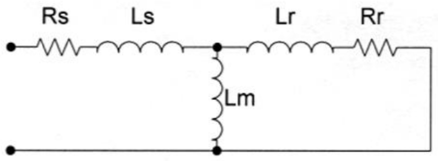


Figure 2. Equivalent circuit for frequencies other than 60Hz fundamental.

I^2R losses occur when current runs through the R_s and R_r resistances. The R_{load} resistance represents the power the motor delivers mechanically to the load. R_{load} is a variable resistance and is sized to represent the output power of the motor. In Fig. 1, R_{load} is not a component of the equivalent circuit for harmonic frequencies, since harmonics do not aid torque production.

The harmonic components of the stator voltages in Fig. 2 are faced with less equivalent impedance. This translates into relatively large harmonic current components running through the stator and rotor resistances, which creates additional heat.

Total Distortion deal with quantifying the effect of non-fundamental components to the voltage (and current) waveform. The Total Distortion analysis focuses on all non-fundamental components. THD is defined, among other places, in the IEEE Standard 519 as Eq. (2) and Eq. (3).

$$THD_V = \frac{\sqrt{\sum_{n=2}^{n_{\max}} V_n^{\,2}}}{V_{RMS}} \tag{2}$$

$$THD_I = \frac{\sqrt{\sum_{n=2}^{n_{\max}} I_n^{\,2}}}{I_{RMS}} \tag{3}$$

This concept appropriately covers all common cases for line operated machinery distortion effects. For line-operated machinery, it is very rare to have noticeable non-harmonic distortion in the voltage signals. At this time, however, Variable Frequency Drives (VFDs) have become a popular solution for many applications. In order to create a certain frequency, VFDs use a variety of switching strategies with which they send positive and negative voltages to the machine alternating with rather high frequencies. The most common strategy to this switching is Pulse Width Modulation (PWM). The PWM method introduces such large distortion to the voltage waveforms, that it can be difficult to find the fundamental frequency among all the switching-induced noise.

Under rare conditions, the VFD can actually generate a higher amount of high frequency switching components, than of the intended fundamental frequency. These voltage components may – perhaps – be located at frequency locations that are at multiples of the fundamental frequency. Only if the switching frequencies fall exactly upon multiples of the electrical fundamental, will the THD equation deliver the appropriately high results. It is far more likely, however, for the switching frequencies to be in-between electrical harmonic frequencies (also called inter-harmonics). The THD calculation, as defined by IEEE Std. 519 will not deliver the appropriately high results in this majority of the cases.

The solution are all frequency components can be viewed as being linearly independent of each other. Their contributions need to be added geometrically to each other to obtain the total RMS, Eq. (4) and Eq. (5).

$$I_{RMS} = \sqrt{\sum_{0}^{F} (i(f))^2} = \sqrt{(i(f_1))^2 + (i(f_2))^2 + (i(f_3))^2 + \ldots} \tag{4}$$

$$V_{RMS} = \sqrt{\sum_{0}^{F} (v(f))^2} = \sqrt{(v(f_1))^2 + (v(f_2))^2 + (v(f_3))^2 + \ldots} \tag{5}$$

The concept of THD aims at dividing the non-fundamental (harmonic) content of the waveforms to the component.

4. VFD - VARIABLE FREQUENCY DRIVE

The Analysis Module Variable Frequency Drive (VFD), available at Baker Explorer 3000 is a new technique for diagnosis of electric motors driven by frequency inverters. This technique is promising and has gained ground in the world market. In Brazil it is still little known to the researchers and practitioners in the Maintenance Area.

The VFD Module lets you monitor the frequency, speed, torque and voltage level with respect to time, allowing the engine to identify transient overloads due to the use of variable frequency. With this feature it is possible to identify and correct the rotation monitoring the actual conditions of engine operation.

Burstein (1996) shows how the analysis of the electrical signal (current phase of a stator) can be used to assess the state of the monitored equipment. Married and Bunch (1996) presented the concept of using an electric motor as a sensor for monitoring their own driven load. Riley et al. (1997) showed that vibration in an electric motor that is exposed can be found in modulated data in the frequency domain of the stator currents.

5. VIBRATION ANALYSIS

The Vibration Analysis is regarded as the most important predictive technique for condition monitoring of rotating machines. According to Crawford Art "currently in the industry, all parameters that can be measured not invasively, which contains more information is the signature vibration." This technique detects both faults such as mechanical origin of electrical origin. For the case of unbalance, misalignment and backlash, the frequencies are deterministic ($1xf_r$, $2xf_r$, $3xf_r$), where f_r is the frequency of rotation, Brito et al. (2001).

According Bonalidi (2008) spectral analysis of vibration signal is markedly impaired when there is presence of frequency inverters.

Brito et al. (2008) presented initial results on the influence of the frequency inverter to detect mechanical faults (unbalance, misalignment and backlash), beyond the normal operating condition, and was considered the fifth best paper presented at the 23rd CBM (Brazilian Congress of Maintenance), which shows the importance of the topic.

6. EXPERIMENTAL TEST

Experimental tests have been developed on a stand, Fig 3, available at the Laboratory of Dynamical Systems (LASID), Department of Mechanical Engineering (DEMEC), Federal University of São João del Rei (UFSJ).

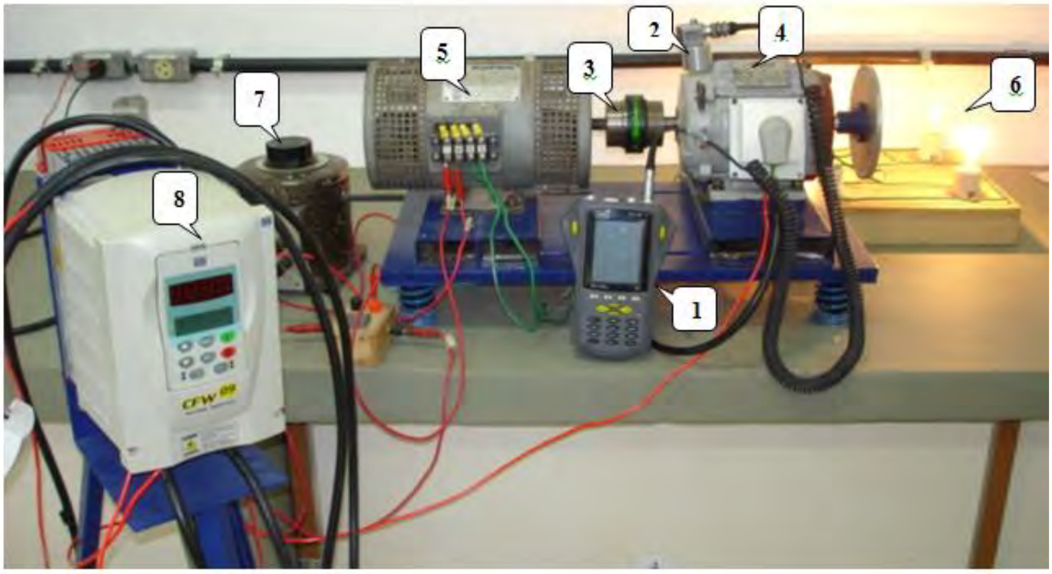


Figure 3. Experimental stand

For acquisition of vibration signals, we used the SKF Microlog GX-75 [1]. This equipment is a collector and signal analyzer that scans the information contained therein. This information can be analyzed directly in the actual equipment or otherwise transferred to the computer through software support SKF @ ptitude Analyst Human Machine Interface. This option has a more comfortable work, allowing detailed analysis, reporting, and mounting the database.

The signals were collected with the accelerometer SKF CMSS2200 [2], with a sensitivity of 100 mV, placed alternately in the vertical position, horizontal, on both the flexible coupling [3] as the next fan of the electric motor.

Changing the power supply was inserted in three phase induction motor [4], Eberle, 1/3 cv, 860 rpm, 220V, 60 Hz, 8-pole, N category, SKF 6204 ZZ, insulation class B, 1 FS , 15, Ip / In 3.5, 55 IP, 1.68 A.

As charging system was used generator (DC motor [5], Kuper, 0.45 kW, 1500 rpm, 220V, 60 Hz, Class F, SKF 6203, 23 IP, 0.45 A), powered by a bank of resistance [6]. To load variation used a varivolt [7] 220 V.

To power the set was used PWM frequency inverter type, WEG CFW 09 [8].

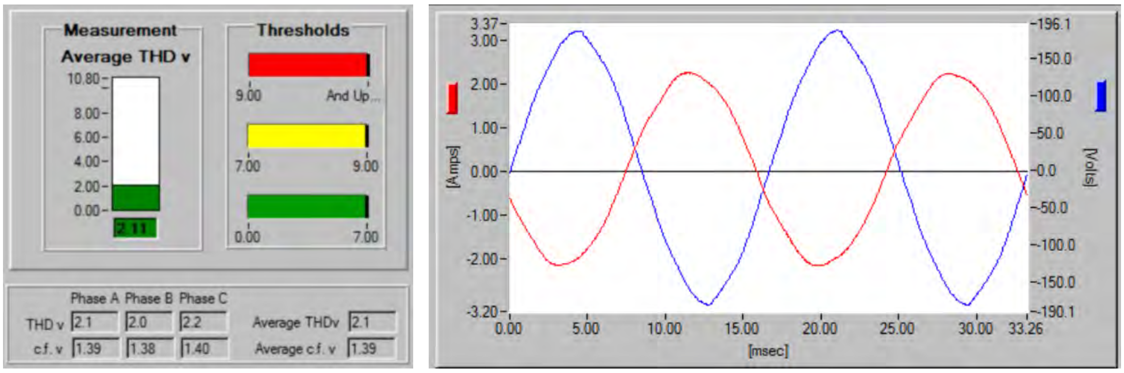
For acquisition of signals through the Analysis Module Variable Frequency and Total Harmonic Distortion, we used the Baker Explorer 3000.

6.1 Test procedure

The tests consist in changing the feeding system in order to verify the influence of a bad power therein. Thus was performed measurements with frequencies of 60Hz inverter with and without the inverter, and conditions with 55Hz, 50Hz, 45Hz and 25Hz with an extreme case.

6.2 THD - Total Harmonic Distortion

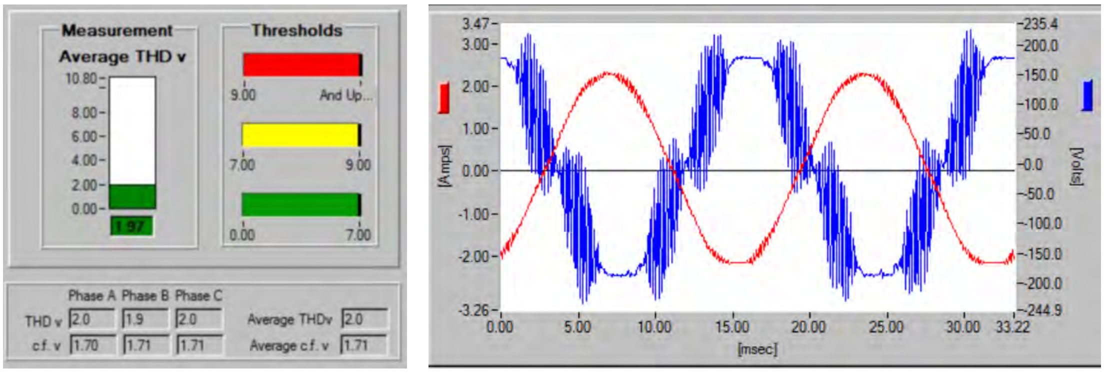
In Fig. 4, has the THD for the engine operating at a frequency of 60 Hz with no drive frequency inverter and the graph of the waveforms.



	Phase A	Phase B	Phase C		
THD v	2.1	2.0	2.2	Average THDv	2.1
c.f. v	1.39	1.38	1.40	Average c.f. v	1.39

Figure 4. Frequency 60 Hz without frequency inverter

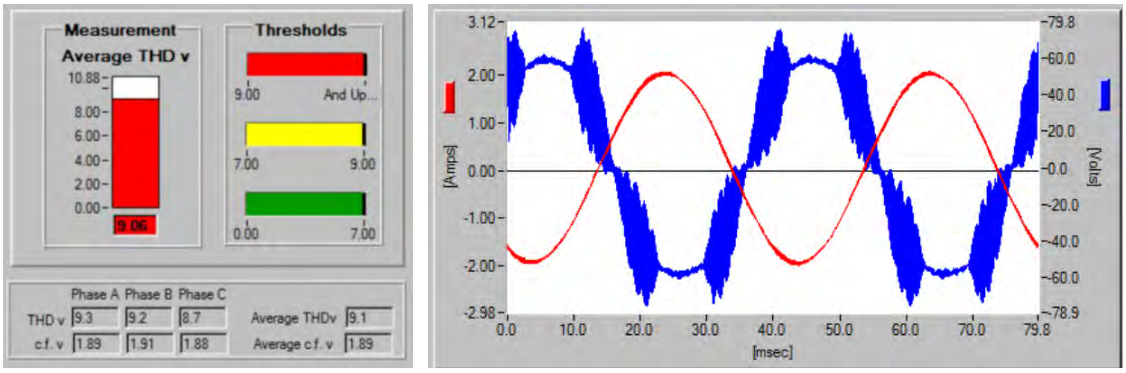
In Figure 5, there is THD for the engine operating at a frequency of 60 Hz but with the frequency inverter. It is evident in this case that when there was a power supply stable and in good condition, the inverter does not significantly influence the number of harmonics distorted. From the spectrum waveform can realize a small distortion sinusoid which describes the system power generated by the inverter, however it does not influence the system operation.



	Phase A	Phase B	Phase C		
THD v	2.0	1.9	2.0	Average THDv	2.0
c.f. v	1.70	1.71	1.71	Average c.f. v	1.71

Figure 5. Frequency 60 Hz with frequency inverter.

By contrast in Fig. 6, which has the engine operating at a frequency of 25 Hz and being driven by the inverter, it´s clearly the influence of a network of power problematic motor drive. Thus spawned a lot of distorted harmonics that significantly influence the performance of the engine. Later, in section 5.3 we will see how this distortion alters the spectrum of engine torque.



	Phase A	Phase B	Phase C		
THD v	9.3	9.2	8.7	Average THDv	9.1
c.f. v	1.89	1.91	1.88	Average c.f. v	1.89

Figure 6. Frequency 25 Hz frequency inverter.

6.3 VFD - Torque and Speed vs Time

The spectrum has Torque and Speed vs. Time for the engine operating at a frequency of 60 Hz with no frequency inverter drive is shown in In Fig. 7

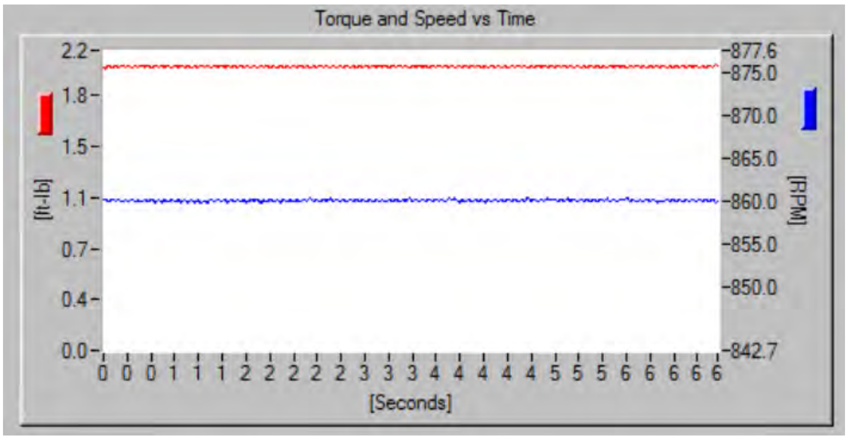


Figure 7. Frequency 60 Hz without frequency inverter

The spectrum has Torque and Speed vs. Time for the engine operating at a frequency of 60Hz actuated by the frequency inverter is shown in In Fig. 8. Thus it is evident that when it maintains a network of ideal power inverter is not directly influence the torque curve of the engine.

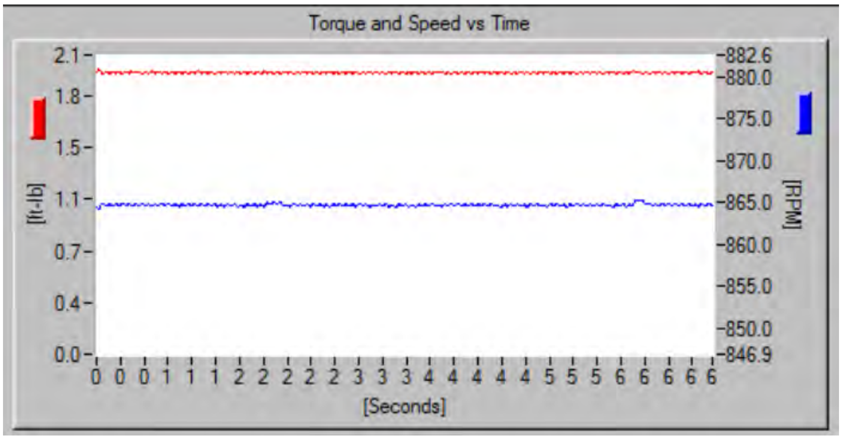


Figure 8. Frequency 60 Hz with frequency inverter

The spectrum Torque and Speed vs. Time for the engine operating at a frequency of 25 Hz actuated by the drive frequency is shown in Fig. 9. It can be observed that the torque chance from constant to harmonic, in the other words, ideal condition due to power the motor torque was greatly influenced by changing its normal operation, thus the rotation was directly affected.

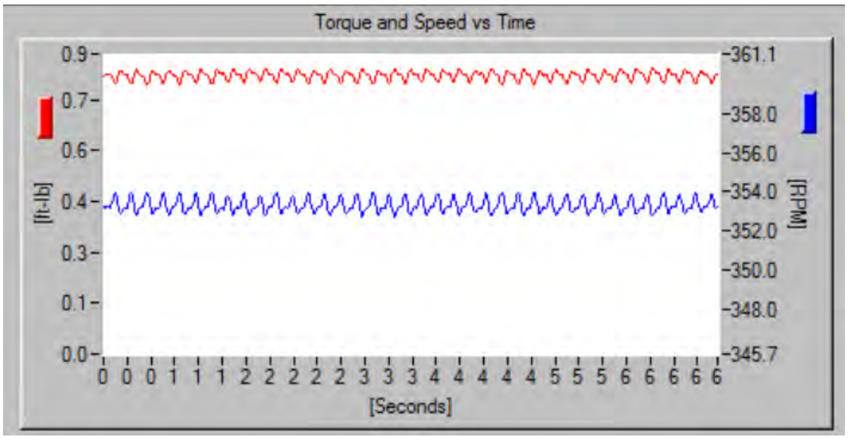


Figure 9. Frequency 25Hz with frequency inverter

6.4 Vibration Analysis

In order to check the influence of the frequency inverter and power supply in an engine, vibration signals were collected from the same. The spectra were collected in the range 5-1000 Hz according to ISO 2372 and ISO 3945.

The tests were performed initially by varying the frequency of 60 Hz, with and without inverter, passing only drive the inverter and the frequency of 55 Hz, 50 Hz and 45 Hz, is shown in Tab.1.

Table 1. Global level (RMS) for certain test conditions.

Test Condition	Global level (RMS)
60 Hz -Without frequency inverter	1.835
60 Hz - With frequency inverter	1.669
55 Hz - With frequency inverter	2.037
50 Hz - With frequency inverter	2.661
45 Hz - With frequency inverter	2.754

Due to the increased THD, the torque becomes harmonic, on other words, with components that increase the vibration levels set in the global analysis. Furthermore it is clear that, globally, the frequency inverter, for a flawless condition evidenced no change the same.

7. CONCLUSION

Analyzing all the parameters studied in this research, it can be concluded that the frequency inverter, when working with a network of adequate food, does not significantly alter the functioning of the whole fire. That is, if the level of TDH is within the standards, the inverter will not be adding harmonic distorted, so the torque will work linearly as expected and consequently no change in the overall level of vibration.

On the other hand, when there has been the problem in the power supply will be generated harmonic distortion in the critical system, i.e., high HDT, which therefore changes the engine torque and thus, due to the harmonics generated there is an overall increase in vibration the system.

Thus the choice of a frequency inverter with good quality and good line filters is essential to achieve the goals of system operation.

8. ACKNOWLEDGEMENTS

The authors express their sincere thanks to the Federal University of São João del-Rei and the FAPEMIG (Fundação de Amparo e Pesquisa de Minas Gerais) that has funded this research.

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